

## LCA Methodology

## Feasibility of Applying Site-Dependent Impact Assessment of Acidification in LCA

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DOI: <http://dx.doi.org/10.1065/lca2005.08.221>**Abstract**

**Goal, Scope and Background.** Taking into account the location of emissions and its subsequent, site-dependent impacts improves the accuracy of LCIA. Opponents of site-dependent impact assessment argue that it is too time-consuming to collect the required additional inventory data. In this paper we quantify this time and look into the added value of site-dependent LCIA results.

**Methods.** We recalculated the acidifying impact for three existing LCA studies: linoleum, stone wool, and water piping systems. The amount of time needed to collect the required additional data is reported. The EDIP2003 methodology provides site-generic and site-dependent acidification factors. We used these factors to recalculate acidification for the case studies. We analyzed differences between site-generic and site-dependent acidification and reported problems experienced.

**Results and Discussion.** Finding the location of processes and emissions was easy. The reports of the three case studies contained most of this information. Far more time was needed to disaggregate processes to the level where emissions can be localized. Although the overall conclusions with regard to acidification did not change in the case studies, the relative importance of processes shifted when considering sub-levels. This is especially important for improvement analysis.

Site-dependent acidification assessment was hampered in the linoleum case study where about 40% of the acidification originates from non-European emissions. However, EDIP2003 provides no site-dependent factors for these countries and site-generic factors had to be used instead. Thus, calculating site-dependent acidification is only feasible for LCA studies in which the majority of the emissions originate in Europe.

We could not reproduce all parts of the three case studies using the report and additional public resources. This hindered our recalculation. In fact, any additional analysis will be hampered by this lack of reproducibility. ISO recommends such reproducibility for comparative assertion disclosed to the public.

**Conclusion.** Spatially differentiated acidification is feasible for each of the three case studies. Finding the location of processes and emissions was easy, but quite some time was needed to disaggregate processes and emissions to the appropriate level. Overall conclusions on acidification remained the same for the case studies, but the relative contribution of basic processes changed when applying site-dependent impact assessment. Though the three case studies were all rather detailed and complete, none of them was fully reproducible. This complicated recalculation of acidification, and will in fact make any additional analysis difficult.

**Keywords:** Acidification; feasibility of site-dependency; Life Cycle Impact Assessment (LCIA); spatial differentiation

**Introduction**

Acid rain in Sweden harms the environment more than acid rain falling on calcareous grounds in southern Europe. This indicates that environmental impact is not always the same for equal amounts of emission released at different geographical locations. However, conventional life cycle impact assessment (LCIA) with hydrogen release potentials does not take into account the location of origin of emissions and how this influences the resulting impact. Site-dependent LCIA includes this aspect by applying characterization factors that depend on the country where the emission takes place and covers site-dependent dispersion, deposition, and ecosystem sensitivity. Hauschild and Potting (2005) exemplify how site-dependent LCIA decreases uncertainty in calculated impact. Opponents of site-dependent LCIA, nevertheless, argue that collecting the required spatial information burdens inventory analysis too much, whereas the results of the LCA hardly change. Using three existing LCA studies, we quantify the effort to collect the additional required data for a site-dependent LCIA and look into the differences between site-generic and site-dependent LCIA results. For a more extended description of the study, we refer to the full report (Bellekom 2004).

In the first place, applying site-dependent LCIA requires information about the location of emissions. However, the inventory table of a conventional LCA does not contain this information and a site-dependent LCIA thus implies an expansion of inventory results. That is, the emissions in the conventional inventory table should be divided into emissions per country. To that end, the processes in our existing LCA studies had to be disaggregated into underlying basic processes to such a degree that the emissions could be localized. The required additional data for a site-dependent LCIA thus consists of the location where each process takes place (location data) and – where necessary – data related to disaggregating processes into the underlying basic processes (basic data).

**1 Approach**

We selected three existing LCA studies for an additional analysis: linoleum (Gorree et al. 2000), stone wool (Schmidt et al. 2003), and water piping systems (Boersma & Kramer 1999). All reports give a detailed description of their LCA, which was the reason to choose them. This paper focuses

only on the impact category acidification. The contribution to acidification is recalculated for each case study, once using a site-generic approach and once using a site-dependent approach. The time needed to collect all the required basic and location data is kept up in relation to the consulted information sources.

Site-dependent LCIA has been and is still discussed within LCA circles. The early paper of Potting and Blok (1994) demonstrated the relevance of spatial differentiation. Thereafter, several authors published sets of spatial differentiated impact factors (Potting et al. 1998, Huijbregts et al. 2000, Krewitt et al. 2001, Norris 2002, Bare et al. 2002). These sets often refer to different definitions of the category indicator and/or are based on different models and data. Potting et al. (2002) and Hettelingh et al. (2005) give a more extensive description and discussion. This paper deals with the application of one set of site-dependent factors. Recalculation of acidification was performed with the help of acidification factors taken from the EDIP2003 methodology (Potting et al. 1998, Hauschild & Potting 2005). These factors express the change in area of ecosystems that become (un)protected as a result of a change in emission in a given country. They are established with the RAINS model (version 7.2) that covers emission, dispersion, and ecosystem sensitivity in a spatially resolved way. RAINS was developed by the International Institute for Applied System Analysis (IIASA) in Laxenburg, Austria. For a description of the calculation method see Potting et al. (1998) or Potting and Hauschild (2005). Besides site-dependent factors, Hauschild and Potting (2005) also provide site-generic factors for unlocalizable emissions and, as suggested in EDIP2003, also for emissions taking place outside of Europe. EDIP2003 calculated these site-generic factors as a weighted average of the factors of the Western European countries (EU15 + Norway and Switzerland).

Applying site-dependent acidification factors to the three case studies involved a number of steps. First, the most acidifying processes or process-steps were selected by applying the site-generic acidification factors from EDIP2003 to the site-generic inventory table of the case studies. Since the level of aggregation of processes or process-steps was very different for the three case studies, selecting the most acidifying processes was not performed uniformly. All processes contributing more than 0.1% to site-generic acidification were selected in the linoleum case study. A level of 0.15% was used in the water piping case study. We selected all process-steps that could be distinguished in the stone wool case.

Second, we disaggregated the selected processes to the level where emissions could be localized (= basic data collection). Especially aggregated processes taken from databases needed further attention. Thorough disaggregation was sometimes required to be able to localize the emissions.

The third step involved locating the disaggregated acidifying emissions to a certain country (= location data). Unlocated emissions and emissions originating in non-European countries were treated site-generically. Transport processes were subdivided into contributions per country on the basis of reported or estimated transport distances per country.

The required time for basic and location data collection per case study was kept up as part of the previous two steps. The required time was distributed over six consulted information sources: 'Report and practitioner', 'digital LCI data', 'producer', 'consulted databases', 'calculated distances', and 'others'. The practitioner clarified parts of the report, therefore studying the report and contacting the practitioner were treated as one information source. Consulting the information source 'digital LCI data' included studying LCI data received in electronic formats and combining data to construct missing information. The required time for actually calculating the impact from the inventory data was not included, though this sometimes required considerable time because existing LCA software does not support site-dependent characterization (yet).

The last step consisted of recalculating acidification with site-dependent impact factors from EDIP2003, followed by a comparison of site-dependent impact results with the site-generic results from the first step. **Text box 1** describes the format in which the results of each case study will be presented.

#### Text box 1: Format for presentation of results

Disaggregated data is for reasons of space not presented in this paper. However, all disaggregated information can be found in the underlying full report (Bellekom 2004). The overall results of each case study are summarized in a figure (see Fig. 1, Fig. 4 and Fig. 7). Each result-figure lists only the most acidifying processes (or process-steps) per case study. The first column in the figure names these processes. The second column, labelled 'information sources', reveals from which sources the data stems. The figure distinguishes aggregated, basic, and location data. The last row in this column summarizes time requirements for data collection per information source. The results of the data collection: localized SO<sub>2</sub>, NO<sub>x</sub>, and NH<sub>3</sub> (and other) emissions per process(-step), are given in the third column named 'emissions'. Each bar in this part of the figure represents 100% of the SO<sub>2</sub>, NO<sub>x</sub>, and NH<sub>3</sub> emissions of the process in question. Different grey tints in the bars denote portions of emissions that could not be localized, were localized within Europe, or were localized in countries outside of Europe. Because for each process the importance of the acidifying substances differs, the last column of the figure shows how each substance adds to site-generic acidification of the selected process(-step). Different patterns in the bars denote the relative contribution of SO<sub>2</sub>, NO<sub>x</sub>, NH<sub>3</sub>, and other substances to the acidification of the considered process(-step). For example, when looking at the case study on linoleum, Fig. 1 shows that for the electricity processes the NH<sub>3</sub> emissions could not be localized. However, the figure also shows (in the last column) that ammonia hardly contributes to the acidification of these processes. Therefore not being able to localize ammonia emissions for these processes is of minor importance.

The collected data enables recalculation of acidification using only site-generic factors and using site-dependent factors (as much as possible). Fig. 2, Fig. 5, and Fig. 8 show the calculated acidification in absolute terms (divided into the selected processes or process-steps), while Fig. 3, Fig. 6, and Fig. 9 depict relative contributions of processes (or process-steps) to the overall acidification of each case study.

## 2 Results for Linoleum

In 2000, the Centre of Environmental Sciences (CML) in Leiden carried out an LCA of linoleum for use in public buildings like schools, hospitals and universities (Gorree et

al. 2000). This LCA was commissioned by Forbo-Krommenie, the world's largest producer of linoleum. The functional unit reads: "the use of 200 m<sup>2</sup> linoleum (produced by Forbo-Krommenie B.V. in 1998) in an office or public building over a period of 20 years". The performed LCA covers the production, use, and disposal stage. The production stage includes the manufacture of linoleum, and transport and processing of ingredients back to resource extraction. The use stage of linoleum covers the use, transport, and cradle-to-gate production of maintenance products. The disposal stage assumes incineration and energy recovery of removed linoleum. Gorree et al. (2000) studied several scenarios, but only the baseline scenario is considered here. This scenario assumes the production, use, and waste processing of linoleum to take place in the Netherlands. For disaggregated data we refer to the underlying full report (Bellekom 2004).

2.1 Effort

Fig. 1 shows the overall results of the data collection part of this case study. Locating the emissions was easy and hardly took any time. The necessary location data was often already provided by the report. The majority of the time was needed for disaggregating inventory data. Travel time and visits to the practitioner and the producer accounted for most of the time related to the information sources 'report and practitioner' and 'producer'. Most time-consuming was disaggregating processes taken from the ETH database (Frischknecht et al. 1995). Also searching for alternative processes to reproduce the confidential TiO<sub>2</sub> process took some time, but unfortunately did not result into useful information. We assumed that 75% of the emissions take place at the TiO<sub>2</sub> production site, the other 25% remained unlocalized. The SO<sub>2</sub> emissions of this process account for 31% of the SO<sub>2</sub> emissions of linoleum, NO<sub>x</sub> contributes 12%. The location of the TiO<sub>2</sub> production is known.

2.2 Relevance

Fig. 2 depicts the acidification of linoleum calculated with site-dependent impact factors (as much as possible) and with site-generic factors. The result for site-dependent acidification shows to be about 15% smaller than site-generic acidification. The reduction of the acidification can be explained by the fact that most processes take place in Western Europe where the acidification factors are a little lower than the site-generic factor. The relative contribution of processes to the total acidifying impact of linoleum shifts when site-dependency is applied, though the major contributing processes remain as important. Only the relative importance of some less important processes changes (see Fig. 3). The additional value of applying site-dependency in the case study of linoleum is thus low. Most options for improvement as formulated in the report (Gorree et al. 2000) do not change after a site-dependent LCIA. The emphasis of the recommendations on linseed and pigment (TiO<sub>2</sub>) is still valid.

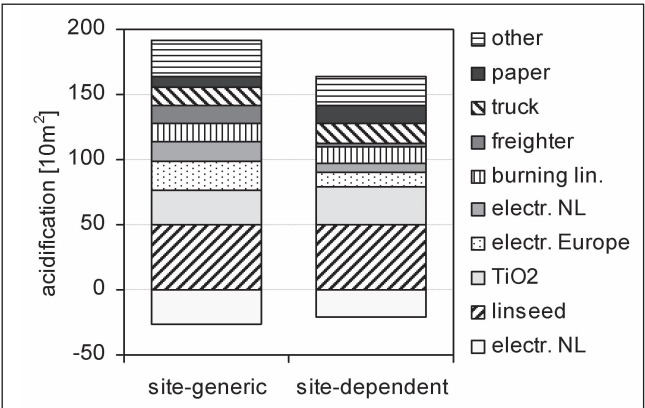


Fig. 2: Recalculated acidification of linoleum (The negative impact relates to energy recovery during incineration of waste linoleum)

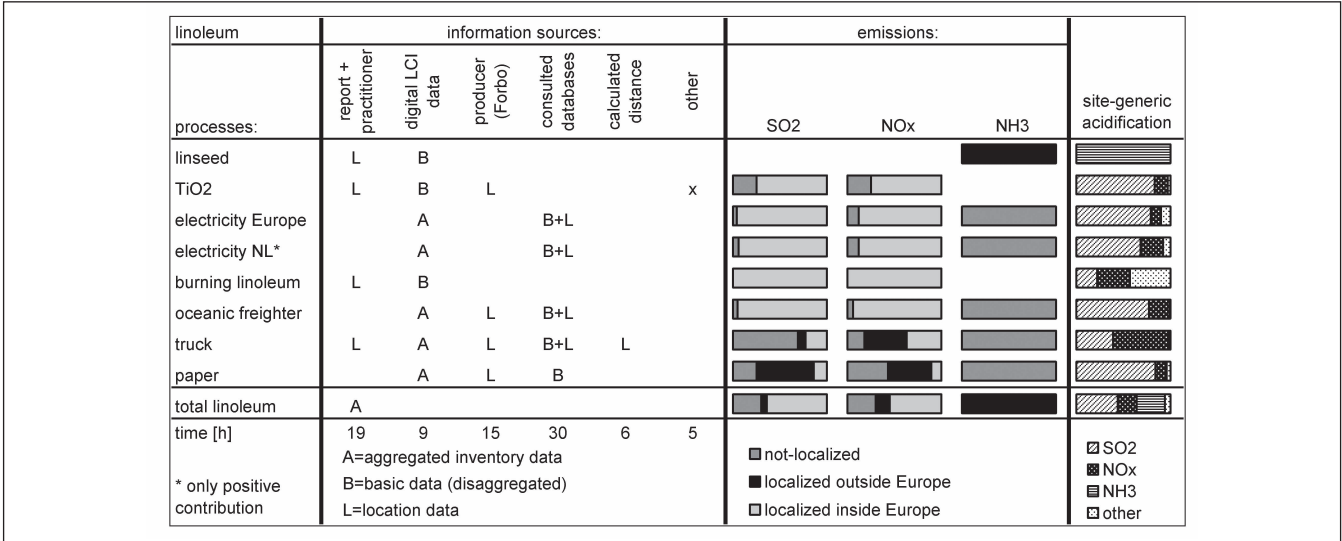
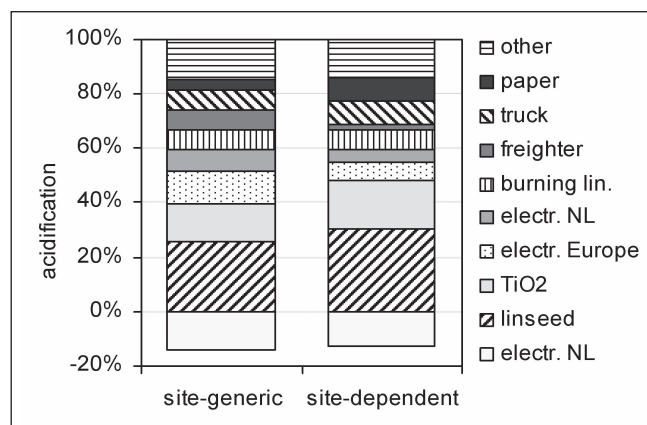


Fig. 1: Results from the localization of emissions from the linoleum case study, for the most acidifying processes. The second column shows from which information source the aggregated inventory, basic, and location data originates. In the last row of this column, the time required to collect data from each information source is given. Each bar in the third column (emissions) represents 100% of the emissions of the process; gray values indicate if and where the emissions were localized. The last column depicts the relative contribution of the acidifying substances to site-generic acidification of each process (see also Text box 1)



**Fig. 3:** Relative contribution of processes to recalculated acidification of linoleum, divided into contributions per process (The negative impact relates to energy recovery during incineration of waste linoleum)

### 2.3 Difficulties

Disaggregating process data introduced more problems than collecting location data. Finding the country of origin was almost always easy (often provided by the report). Disaggregating processes into basic processes and finding the emissions of these basic processes per functional unit turned out to be far more difficult than locating the emissions. Confidential processes, like the production of  $\text{TiO}_2$ , make it even impossible to disaggregate and localize emissions of these processes.

Absence of site-dependent factors for non-European emissions prevented the calculation of site-dependent acidification for those emissions. This reduced the maximum amount of emissions to be assessed with site-dependent acidification factors.

## 3 Results for Stone Wool

In 2003, dk-Teknik Energy & Environment together with Rockwool International performed an LCA of insulation materials (Schmidt et al. 2003). They compared stone wool, flax,

and paper wool using as functional unit: the amount of material required to insulate  $1 \text{ m}^2$  with a thermal resistance of  $1 \text{ m}^2 \text{ K/W}$  during 50 years. Paper and flax insulation are not considered since these materials are hardly used as insulating materials nowadays. This paper focuses on the 'stone wool production in Denmark', with a functional unit of 1.184 kg.

The stone wool LCA involved manufacturing, packaging, distribution, and disposal of stone wool, and production and transport of raw materials for briquettes and binder (ingredients of stone wool). Schmidt et al. (2003) studied these six process-steps separately. We followed the same approach, but separated the emissions of the manufacturing of stone wool into emissions from electricity generation used for the production process and direct emissions at the production site. The report (Bellekom 2004) describes the disaggregation and localization of the inventory data in detail, while we present overall results here.

### 3.1 Effort

Fig. 4 lists the hours spent on consulting different data sources (second column, last row). Similar as for linoleum, collecting location data took far less time than collecting basic data. All location data could be found in the report, but this was not the case for the necessary basic data. Intensive e-mail contact with the practitioner accounted for about half of the time related to the information sources 'report and practitioner'. 'Digital LCI data' also covers the mathematical deduction of an approximated composition of the briquettes and binder. Time spent in the column 'other' refers to attempts to reveal the composition of stone wool. The producer could not help us with the recipe of stone wool since this is confidential. The majority of the total effort relates to briquette and binder production. These process-steps only contribute to acidification to a minor degree (see Fig. 6). Collecting data for site-dependent acidification of the most acidifying process-step, labeled 'direct emission at production site', required hardly any time.

stone wool	information sources:							emissions:			site-generic acidification
	report + practitioner	digital LCI data	producer (Rockwool)	consulted databases	calculated distance	other		SO <sub>2</sub>	NO <sub>x</sub>	NH <sub>3</sub>	
process-steps:											
direct emission at production site	A+L	B	L								
electricity in production process		A		B+L							
briquette production	A+L	B		B+L	L	x					
binder production	A+L	B			L						
distribution		A		B	L						
other		A									
total stone wool	A										
time [h]	19	14	2	8	3	3					
	A=aggregated inventory data B=basic data (disaggregated) L=location data						■ not-localized ■ localized outside Europe ■ localized inside Europe			■ SO <sub>2</sub> ■ NO <sub>x</sub> ■ NH <sub>3</sub> ■ other	

**Fig. 4:** Results from the localization of emissions from the stone wool case study, for the most acidifying process-steps. The second column shows from which information source the aggregated inventory, basic, and location data originates. In the last row of this column, the time required to collect data from each information source is given. Each bar in the third column (emissions) represents 100% of the emissions of the process-step, gray values indicate if and where the emissions were localized. The last column depicts the relative contribution of the acidifying substances to site-generic acidification of each process-step (see also Text box 1)



### 3.2 Relevance

Fig. 5 shows the results of recalculating site-generic and site-dependent acidification for stone wool. Direct emissions at the stone wool production site make up the majority of the emissions (60% of  $\text{SO}_2$ , 20% of  $\text{NO}_x$ , and 100% of  $\text{NH}_3$ ). The difference between site-generic and site-dependent acidification is therefore mainly caused by the difference between site-generic and Danish acidification factors. Site-dependent acidification is more than twice as large as site-generic acidification. See Fig. 6 for the relative contribution of processes to the total acidifying impact changes when site-dependency is applied.

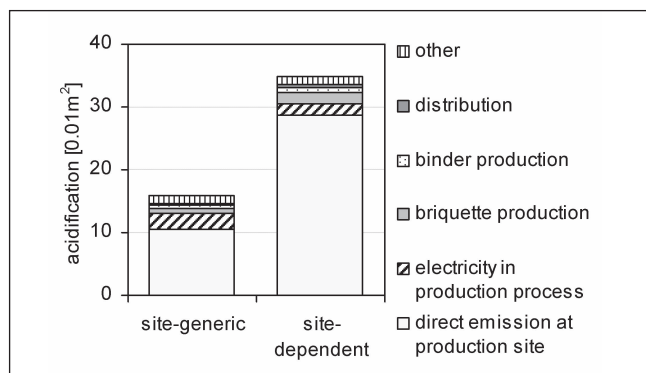


Fig. 5: Recalculated acidification of stone wool, divided into contributions per process-step

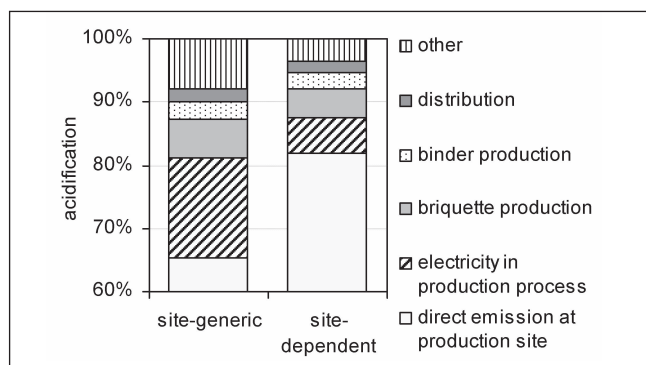


Fig. 6: Relative contribution of process-steps to recalculated acidification of stone wool. Note: the vertical axis does not start at zero

The goal of the original LCA study is to compare three types of insulating materials. Since we analyzed only one of them, possible changes in preference cannot be determined. However, changes in relative contributions of the processes will influence improvement studies. Direct emissions at the stone wool production site become much more important when acidification is calculated site-dependently instead of site-generically. Improving the production process will reduce the acidification of stone wool substantially.

### 3.3 Difficulties

Collecting basic data introduced more difficulties than the easy to find locations. The stone wool LCA (Schmidt et al. 2003) and reference databases (e.g. Frees & Weidema 1998)

revealed all location data. However, full reproduction of the original LCA turned out to be impossible due to confidentiality of some processes and compositions.

## 4 Results for Water Piping Systems

In 1999, the Consultancy and Research for Environmental Management (CREM) performed an LCA on water piping system in the Netherlands (Boersma & Kramer 1999). They compared six water piping systems for the Netherlands: copper, copper with light alloy, PE-X, Al/PE-X, PP-R, and PVC-C. Copper water pipes are the traditional system. Although acidification has been recalculated for each of the six water piping systems, only traditional copper piping will be quantified here in detail. The other five systems will only be discussed in a qualitative way. For a more extended description of the recalculation, including disaggregated data, we refer to the report (Bellekom 2004). The functional unit consists of a standardized water piping system with a functional life of 50 years.

The water piping system LCA covers three stages: production, use, and disposal. The cradle-to-gate production stage of the LCA includes several components of water piping systems, like tubes, braces, solder, etc. The use stage consists of heat losses and corrosion of copper water piping. Heat loss mostly occurs when heated water is transported through the pipes. It is composed of two parts: energy required to heat the water (using gas) and the purification of lost drinking water (requiring electricity). The loss of drinking water occurs when you keep the tap running until the water is warm. The use stage takes place in the Netherlands. For each disposed material, a distinction is made between incinerating, dumping, and recycling.

### 4.1 Effort

Fig. 7 shows the amount of time we required for data collection. Time required for spatial data collection related to the most important process, 'MJth gas' in the use stage, is almost zero as the use stage by functional definition takes place in the Netherlands and as the process does not need further disaggregation. This process contributes 91% to site-generic and 93% to site-dependent acidification of copper water piping systems. 'MJth gas' models the combustion of gas in the water heating device, while heating water that is lost. Thus, a major part of the acidification could very easily be calculated site-dependently. The remaining effort relates to processes that only contribute marginally to acidification.

Most time was spent on studying references related to copper production. Reading literature about copper production and surfing on Internet to find production locations took about 8 hours. This information was used to localize emissions from the processes 'heat oil' and 'primary copper', which contribute 0.8% and 0.2% to site-generic acidification of copper water piping systems. As a second major time consumer, studying 'nylon 66' inventory data and localizing production sites added up to almost 4 hours. Also, this process only contributes slightly to site-generic acidification: 0.3%. Understanding the processes that generate emissions related to gas production ('gas NL') asked for another 2 hours.

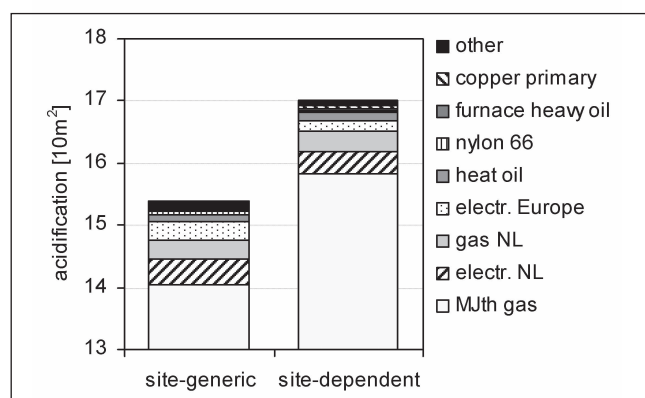
water piping	information sources:						emissions:			site-generic acidification
processes:	report + practitioner	digital LCI data	producer	consulted databases	calculated distance	other	SO <sub>2</sub>	NO <sub>x</sub>	NH <sub>3</sub>	
MJth gas	L	B								
electr. NL		A		B+L						
gas NL		B+L		B		L				
electr. Europe		A		B+L						
heat oil		A+B		B		L				
nylon 66		A		B		L				
furnace heavy oil		A				B+L				
copper primary		A+B				L				
total water piping	A									
time [h]	8	10				together 21				
	A=aggregated inventory data B=basic data (disaggregated) L=location data						■ not-localized ■ localized outside Europe ■ localized inside Europe			■ SO <sub>2</sub> ■ NO <sub>x</sub> ■ NH <sub>3</sub> ■ other

**Fig. 7:** Results from the localization of emissions from the water piping case study, for the most acidifying processes. The second column shows from which information source the aggregated inventory, basic, and location data originates. In the last row of this column, the time required to collect data from each information source is given. Each bar in the third column (emissions) represents 100% of the emissions of the process, gray values indicate if and where the emissions were localized. The last column depicts the relative contribution of the acidifying substances to site-generic acidification of each process (see also Text box 1)

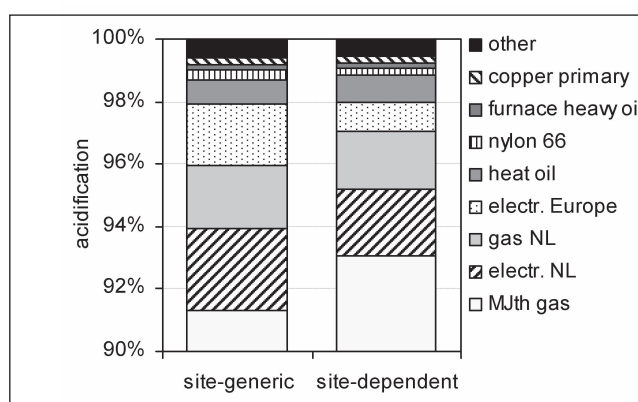
## 4.2 Relevance

Fig. 8 depicts the recalculated acidification of copper water piping. The 'MJth gas' process in the use stage is the dominant process, also for the other five water piping systems of the case study. This process only emits the acidifying substance NO<sub>x</sub>. The acidification of 'MJth gas', and therefore of almost the overall case study, changes according to the difference between site-generic (0.86 × 0.01 m<sup>2</sup>/g) and Dutch (0.97 × 0.01 m<sup>2</sup>/g) acidification factors for NO<sub>x</sub>. The resulting total acidification calculated according to the site-dependent approach is about 10% higher than site-generic acidification.

The order of most acidifying water piping systems did not change when site-dependent instead of site-generic factors were used to calculate the acidification of each of the six systems described in the report (Boersma & Kramer 1999). However, the relative contribution of the processes to the system's acidification does change, like it did for the other



**Fig. 8:** Recalculated acidification of copper water piping system, divided into contributions per process. Note: the vertical axis does not start at zero



**Fig. 9:** Relative contribution of processes to recalculated acidification of copper water piping system. Note: the vertical axis does not start at zero

two case studies. Site-dependent acidification of the process 'electricity Europe' is less than that of 'heat oil', while the opposite is true in the site-generic case (Fig. 9). However, both processes contribute less than 1% to site-dependent acidification of the copper water piping system. The most important process, labeled 'MJth gas' in Fig. 9, stays the most important process for all six water piping systems.

## 4.3 Difficulties

Since no actual producers of copper or copper water pipes were available, we used world wide copper trade statistics to estimate the location of the emissions related to copper production. It would be more accurate to know the producers of copper water pipes and their share in the use of those pipes in the Netherlands, followed by detecting the actual producers of copper where the copper water pipe producers buy their copper, etc. The same applied for nylon 66.

## 5 Discussion

**Table 1** summarizes the time required to get all basic and location data necessary for site-dependent LCIA of acidification for each case study. Finding location data turned out to be easy for each of the three case studies in this paper as the report usually provided this information. The feasibility of a site-dependent LCIA was hampered by difficulties to disaggregate some processes into basic processes and finding the emission of basic processes per functional unit. Most effort (time) was spent on disaggregating and localizing processes that contribute only a little to acidification. Localizing the most important processes did not require much time.

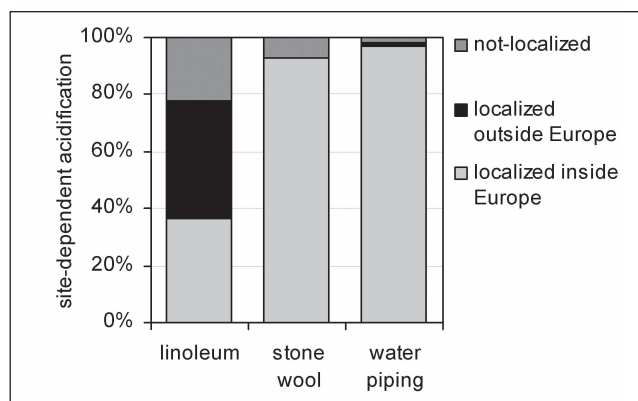
We estimated the extra time for site-dependent calculation of acidification if this would have been taken into account right from the start of the LCA (last column of Table 1). This time is obviously less than the time for our additional analysis, since the performer then already has most of the required data at his disposal. The main additional effort consists of disaggregating database processes. This only has to be done once, however, because the disaggregated information can be used again.

To all three case studies applies that only a few processes determine the majority of the acidification. In the linoleum case study 'growing linseed' and 'production of  $\text{TiO}_2$ ' together contribute to 46% to site-generic acidification of linoleum. 'Direct emissions from the production site' dominate acidification in the stone wool case study with a contribution of 65%. The water piping system LCA shows the strongest dominance of one process: 'MJth gas' explains 92% of the site-generic acidification. Studying only these processes already results in a high portion of localized acidification at much lower effort. The same will be true for other impact categories.

The results exemplify the effort required for data collection related to site-dependency of one impact category: acidification. Considering other impact categories will not require much additional time since a lot of (unit) processes are already localized and disaggregated into basic data.

**Fig. 10** depicts the relative amount of acidification that could be localized and for which site-dependent factors are available (emissions localized inside Europe), and the relative amount of not-localized emissions and emissions localized outside of Europe for which site-generic factors are used. The figure clearly shows that the linoleum case study suffered most from the absence of site-dependent acidification factors for emissions taking place in countries outside of Europe. The lack of such acidification factors limits a site-dependent treatment of emissions originating from these countries. Site-dependent acidification is presently therefore only feasible when the majority of the emissions take place in European countries.

Emissions were considered localized when the country of origin was known. The spatial resolution of the site-depend-



**Fig. 10:** Results of site-dependent calculation of acidification of three case studies

ent acidification factors used roughly corresponds with European countries. Outside of Europe, emissions were localized in regions the size of the USA or Canada. These countries are much larger than the European ones, so the spatial resolution for these emissions is less. Because of the lack of compatible site-dependent acidification factors for countries outside of Europe, not much time was spent on trying to localize non-European emissions more accurately.

Site-dependent LCIA for acidification can change the relative importance of unit processes. The overall picture for acidification did not change for the three case studies. In two of the case studies, one process dominates the acidifying impact and the emissions from that process take place in countries with impact factors similar to the site-generic ones. This limited relevance of our site-dependent LCIA therefore heavily depends on the selected case studies. We advocate performing more site-dependent LCIA to further explore the relevance of site-dependent LCIA. Also LCAs considering processes taking place in non-western parts of Europe should be included.

Another gain from applying site-dependent impact factors, instead of site-generic impact factors, is the reduction of uncertainty in the result. Uncertainties related to the location of the emission are reduced. However, other uncertainties remain. For example, uncertainties of the (site-dependent) impact factors themselves will influence the results. Hettelingh et al. (2005) recently published updated, site-dependent impact factors including values for uncertainty in the calculated acidification.

The selected case studies are suitable for additional analysis because they are documented comprehensively. Though all reports were rather complete, difficulties nevertheless occurred because the LCA studies were not fully transparent and reproducible. That is, the reports did not contain all information required to redo the impact calculations (some-

**Table 1:** Time spent by the performer to do the original LCA, and time needed for additional data collection required for site-dependent acidification

Case studies	Initial time spent on LCA (by performer)	Effort for additional analysis	Estimated effort right from the start
Linoleum	480 h	84 h	46 h
Stone wool	167 h	49 h	11 h
Water piping systems	300 h	39 h	10 h

times because of confidential processes). The three case studies were selected on the basis that a full report was available. A first attempt to choose LCA studies published in scientific magazines failed because they usually provided only overall LCA results and did not refer to a full (publicly available) background report. Although the ISO (ISO 14041 1998) requirements towards reproducibility are not elaborated in detail, the spirit is that an independent practitioner should be able to redo the LCA (especially when the LCA is "used to support a comparative assertion that is disclosed to the public"). A partial lack of reproducibility makes all kinds of additional analyses on existing LCA studies difficult, not only recalculating the acidifying impact with site-dependent factors.

To perform any additional analysis on existing LCAs, reproducibility of the LCA is an important issue. In a recent article in the international journal of LCA, Frischknecht advocates (more) transparency in LCA (Frischknecht 2004). He relates transparency to making all data public, not using confidential processes, and enabling reproduction of an LCA.

In a recent survey (Stewart & Goedkoop 2003), LCA practitioners rank transparency of LCIA as the most important item. The respondents to the survey could give additional comments, one said: "With reference to transparency: Something may be transparent for one person (with a given background) but not for another. So transparency must be defined in relation to a receptor. LCIA methodology must be: 1) basically understandable for a person with a general school education (i.e. the principles can be understood), and 2) reproducible for a specialist (i.e. she or he is able to reproduce and possibly falsify the calculations)" (Stewart & Goedkoop 2003). Note that reproducibility is included here in transparency.

## 6 Conclusion

Spatially differentiated LCIA for acidification turned out to be feasible for our three case studies. Determining the location was usually easy. Most effort was required for disaggregating processes and emissions to the appropriate level. Site-dependent acidification did not change the overall picture of acidification in the three LCAs that were studied, though shifts in relative importance of the processes occurred when considering sub-levels (important for improvement analysis). The limited relevance of our site-dependent LCIA is caused by the fact that the selected case studies are all dominated by a few processes with impact factors similar to the site-generic ones. To fully explore the worth of site-dependent LCIA, we advocate the application of this method in more LCA studies. Absence of site-dependent factors in EDIP2003 for non-European countries prohibited site-dependent assessment of acidification for processes outside of Europe.

All three case studies were rather detailed and complete, but some processes were described at a general level only and could not be disaggregated (e.g. due to confidentiality). This lack of reproducibility hampered the easy recalculation of acidification and will in fact make any additional analysis difficult.

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